EFFECT OF STRAINAGEING ON WELDED

OR

NONWELDED LOW CARBON STEEL

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENT FOR THE DEGREE OF

Bachelor of Technology
in
Metallurgical and Materials Engineering

By
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CERTIFICATE

This is to certify that the thesis entitled, "EFFECT OF STRAIN AGEING ON WELDED OR NONWELDED LOW CARBOB STEEL" submitted by ANKUR GAUR in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Metallurgical and Materials Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university/institute for the award of any degree or diploma.

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ABSTRACT

An investigation has been performed on the strain ageing of welded and non-welded specimen of low carbon steel. It was determined that the low carbon steel were susceptible to strain ageing in interstitial solutes. The increase in yield strength, tensile strength and elongation because of strain ageing has been compared between welded and non-welded specimen. At high level of prestrain, the percentage loss in ductility was observed. Increase in the strain-ageing temperature the value of ΔY increased, increase the time of ageing has also got influence on value of ΔY. However the influence of temperature of ageing is much more pronounced than the affect of time of ageing. The change in yield stress due to strain ageing in welded specimen was observed less than the non welded specimen. this increase in yield stress is attributed to the fact that the dislocation density of welded sample is higher than non-welded sample.

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INTRODUCTION

1-BACKGROUND ------

YIELD POINT IN METALS----

A tensile test provides the basic data about mechanical properties of metals. The initial linear portion of load elongation or stress strain curves is the elastic region within which Hooke's law is obeyed with the maximum point called elastic limit, but the modulus of elasticity (E=σ/e) remain the same. An ideal brittle material like glass, fracture at the elastic limit without any plastic deformation white cast iron a brittle material shown little plasticity before fracture (yield and tensile strength are practically identical). Brittleness is not an absolute property of a metal. For example plain low carbon steel though ductile at room temperature becomes brittle below its transition temperature or a metal, may be brittle in tension but ductile under hydrostatic compression or a ductile metal at room temperature becomes brittle by lowering the temperature or due to the presence of notches, by high rates of straining or by precipitation of brittle phase at grain boundaries etc.

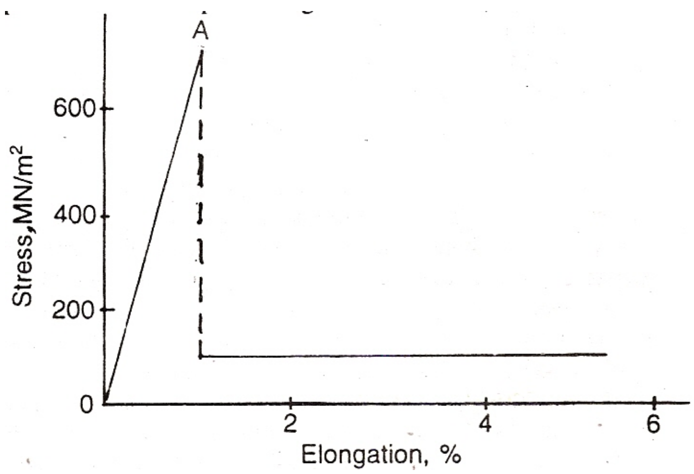
Stress-strain curve of a thin copper whisker (dislocation – free) is illustrated in Fig 4.88 Yielding begins at the stress required to create dislocations in the perfect lattice i.e. upper yield stress approaches the theoretical yield strength of about 700MNm^{-2}. If a dislocation is introduced accidentally for example at the surface the crystal abruptly loses its strength and there is a large decrease in the stress required to cause further strain which is permanent. Once multiplication of dislocations starts the stress to glide this dislocation is several magnitudes lower. Such a behavior of drop of stress from upper to lower yield point is also common in inherently hard nearly perfect crystal of non metallic materials such as silicon or germanium etc.

The start of general yielding in polycrystalline material occurs at a stress at which the dislocation sources (Frank-Read sources) can create slip bands in metals. The general yield stress σy is:

$\sigma y = \sigma s = \sigma i$

Where σs is the stress needed to operated a source and σi is the friction stress which represents the combined effect of all the obstacles (like foreign atoms vacancies precipitates etc) opposing the motion of a dislocation just created the σy us usually 10^{-3}G to 10^{-2}G where G is the shear modulus.

In annealed mild steel most of the dislocation are pinned by segregated carbon and nitrogen atoms (if present). These pinned dislocations are usually not freed by the applied stress and thus new dislocation are generated.



Copper whisker elongates elastically till a dislocation is created, and then deforms plastically with a large decrease in stress required to cause further strain.

LUDERS BAND FORMATION -----

Stress strain curve of low carbon steel shown an abrupt or sharp yield point Fig. 4.89. Here load increase steadily with elastic strain to a certain high value drops suddenly, and then fluctuated about some constant value of stress, and then rises steadily again as the specimen work-hardens. The stress at which the sudden drop occurs is called the upper yield point. The average constant load to which the drop occurs is called the lower yield point. The average constant load to which the drop occurs is called *the lower yield point,* and the elongation associated with this load is called *yield point elongation (or Luder strain),* which could be of over 10 percent. This deformation is localised and heterogeneous. A peculiar feature of this curve is that the stress required to maintain plastic flow, immediately after yielding has started, is lower than that required to start it, *i.e.,* sharp drop in stress occurs from A to B.

The arrival at point A, the upper yield point is indicated by the formation of one or more of discrete bands of deformed metal (on the surface of the specimen), often visible with naked eye *called Luders bands.* Luders bands are markings on the surface of mild steel specimen, Fig. 4.89, distinguishing those parts of the specimen which have yielded from that which have not. Luders bands are generally at approximately 45° to the tensile axis. The band formation starts at a point of stress-concentration such as fillets, or the end of the grip of the machine. The boundary of the Luders band is called *Luders-front.* Before a Luders band can propagate further, the local stress at the leading edge of the Luders-front must at least be equal to the upper yield stress. This is possible because stress concentration occurs in the vicinity of the Luders front when the applied stress is exerted. The stress concentration arises as a result of a boundary at the Luders front where elastic material is in contact with the plastically deformed material. As the specimen undergoes the stage of yield point elongation, Luders bands spread along the specimen, and coalesce until all the gauge length has been overstrained, and the yield point elongation has been completed. Luders band is a macroscopic band crossing all the grains in the cross-section of a polycrystalline specimen (these are not slip lines), and thus, edges of the band are not necessarily the traces of the individual slip planes. Normally, several bands may form at several points of stress concentration, and lower yield stress is the stress required to propagate Luders bands. Howevers, the value of the lower yield stress depends on the number of Luders front propagating. If first Luders band can be made to be in the middle of the test specimen, then upper yield stress can be twice the lower yield stress, although, it is more usual to obtain the upper yield point 10 to 20 percent greater than the lower yield point.

Recent explanation of Luders band formation is as follows: In polycrystalline materials, the preyield microstrain takes place in a few grains, *i.e.,* slip bands will traverse some of the grains at stresses below the upper yield point. Before a slip band can cross a grain, the pile-up of dislocations should produce a stress-concentration at its tip, which combines with the applied stress to activate in the next grain, a source of dislocation there to create new dislocations, or unlock dislocations, and to propagate the dislocations across the next grain along the operative slip system. As the stress increases, slip bands propagate through several grains in a group because the increased stress increases the dislocation velocity rapidly and, as the length of pile-up increases, the stress concentrated at the tip increases, letting the slip bands to cross more grains. Now, once the entire cross section has been traversed, a Luders band has formed. As the local reduction in cross section (where Luders band had formed) takes place, the Luders front has many points of stress concentration, and thus, the Luders band is continuously propagated over the gauge length of the specimen at a nearly constant stress of lower yield point. The upper yield point is the stress at which prematurely yielded zones can trigger yield in adjacent grains. The yield at lower yield point is essentially the same process, but occurs at a lower stress, because there are so. Many places existing along the front of a fully developed Luders band where stress concentration takes place, *i.e.,* where triggering can take place. Such a yielding phenomenon in mild steel is the exception rather than the rule.

Luders bands frequently form in drawing and stamping operations of low carbon steels. Rough surfaces are developed due to uneven spread of Luders. bands. These surface markings in relief are called *stretcher strains,* or worms, or Hartmann lines. It is a defect as it is bad in appearance, Fig. 4.90, having flame like patterns of depression in the finished surface, and is thus, a cause of concern to manufacturers who stamp, or draw mild steel to get objects such as automobile bodies. Its presence is directly associated with the presence of sharp yield point in the stress- strain curve of the material, and is due to the yield-point elongation. The common solution to this problem is to give the steel sheet a small cold rolling, usually 1/2 to 2 percent reduction in thickness, which is called 'temper rolling, or skin-rolling treatment' just before drawing or stamping the steel . This changes the stress-strain curve as indicated by dotted line in Fig. 4.89. A non-strain ageing steel (having elements like Ti, Nb, V, Cr, Mo, which have strong affinity to form carbides, or nitrides, *i.e.,* carbon and nitrogen are removed from the dissolved state by these elements) can also be used.

THEORY OF SHARP YIELD POINT-----

The sharp yield point phenomenon, particularly the sharp upper yield point and the lower yield point was originally seen in low carbon steels. Such a yield behaviour has been associated with the presence of small amounts of interstitial carbon, or nitrogen (0.001 percent of element) in BCC-iron, since the sharp yield point can be removed by annealing such a steel at 700°C in wet-hydrogen atmosphere. This treatment decarburises the steel. Also, if the above decarburised specimen is exposed further to an atmosphere of dry hydrogen containing a trace of hydrocarbon at 700°C for just a minute, i.e. the steel gets carburised, then the yield point, and its related phenomenon are again observed.

More recently, the yield point has been accepted as a general phenomenon as it has been observed in a number of metals and alloys, although the effect is particularly strong in BCC metals with interstitial atoms such as in oc-Fe (also in Mo„ Nb, V, beta-brass). The HCP metals like Cd and Zn also exhibit this due to the presence of interstitial nitrogen. FCC alloys like copper and aluminium based alloys, also show yield point behaviour though to a lesser degree. The presence of interstitial, or substitutional impurities has been associated with the yield point in these materials.

Cottrells theory of formation of Cottrell's atmosphere, Fig. 4.87 around the dislocations has been used to explain the occurrence of sharp yield point in low carbon steel. According to this theory, carbon or nitrogen atoms in BCC-iron, i.e. in ferrite phase, diffuse to the positions of minimum energy, Fig. 4.87, just below the extra plane of atoms in a positive edge dislocation to reduce the total distortional energy. The elastic interaction is so strong that carbon atoms (or nitrogen atoms) completely saturate to form a row of atoms along the core of the dislocations. This segregation is *called the Cottrell's atmosphere.* The dislocation are thus pinned or anchored. Additional stress over that normally required for the movement of the dislocations is needed in order to tear some of the dislocations away from their restraining impurity atoms. This results in the increase in stress, which sets some dislocations in motion, and corresponds to the upper yield point stress. When the dislocation line is pulled free from the influence of the solute atoms, it can slip at a lower stress, called the lower yield point stress. A significant attraction of this theory is that only a very small concentration of interstitial atoms is needed to produce locking, or pinning along the whole length of all dislocation lines in annealed low carbon steel. See solved problem 4.16, for a dislocation density of 10 lines cm^{-} in low carbon steel, a carbon concentration of 10 would be sufficient to put one interstitial carbon atom per atomic plane along all the dislocation lines present, *i.e.,* to saturate the dislocations. The formation of the Cottrell's atmosphere requires the diffusion of carbon or nitrogen atoms to the dislocation lines, which has been seen to occur as these interstitial atoms diffuse easily and faster even at 20°C to 150°C.

Cottrell's explanation for the increased stress, associated with the upper yield point, to be due to the interaction of interstitial carbon, or nitrogen with the dislocations, and thus locking them, appears' to be correct, but whether, or not the upper yield point is associated with a simple tearing away of dislocations (unpinning) from their atmospheres is a doubtful controversy. It was found that die provisions of free dislocations, for example, by scratching die surface of the specimen, did not eliminate the sharp yield point Moreover, materials like germanium and copper whiskers, which have very low density of dislocations, too exhibit sharp yield point, and impurity-unpinning of dislocations cannot explain the yield point phenomenon.

An alternate theory by Johnston and Gilman has been developed. As carbon (also nitrogen) atoms strongly anchor the dislocations (screw as well as edge as explained earlier), *new dislocations must be generated,* and the stress has to be increased to a high value called upper yield point stress. Thus, *very few free dislocations are available* at die start of the plastic deformation near the upper yield point of the mild steel. Once the deformation starts, rapid multiplication of new dislocations takes place. As the average velocity of fresh dislocations depends on die applied stress as:where, v is the average velocity of dislocation, an is the stress corresponding to unit velocity (= 157 ± 5 MPa) and a is the yield stress, *m* is die index characteristic of the material (varying between 1 and 60).

The tensile testing machine used for testing on an average gives a constant strain rate, which is given by,Constant strain rate, where, p is the density of mobile dislocations; *b* is die Burgers vector of die dislocations, and v is die average velocity of dislocations. As die strain rate is constant, then from equation (4.69)

where, Pu and Vu are density and average velocity of mobile dislocations respectively at upper yield point; PL and VL are density and average velocity of mobile dislocations respectively at lower yield point. As velocity is dependent on die applied stress as per equation (4.68), thus, combining with the equation (4.70),

where, σU and σL stresses at upper yield point and at lower yield point respectively. The ratio $\sigma U/\sigma L$ is large, i.e. mere is a large drop in yield stress, if *m* is small, and ρL is much larger then ρU. If at the upper yield stress, die density of mobille dislocations is low (such as due to solute-atom locking), a large drop in yield stress occurs, if a large number of new dislocations are generated. This is true in low carbon steel, as the dislocations are anchored by the Cottrell atmospheres of carbon, and or nitrogen atoms. The application of high stress at upper yield point is not usually able to tear the locked dislocations, but new dislocations are generated at points of stress concentrations like grain corners, grain edges, interfaces,

boundaries, and rapid multiplication of new dislocations occurs. Observations indicate that the dislocation density just after the lower yield stress is much higher than that observed at the upper yield point.

In low carbon steel, initially the dislocations are strongly anchored, the only way the strain rate remains constant (ρ b $\bar{v}$) is by increasing average velocity v of the dislocations (whatever are generated). But as v is strongly dependent on the stress, it can be achieved by increasing the stress, *i.e.,* the stress rises. This makes the less favourable dislocation sources to become operative, *i.e.,* not only the dislocations are generated, they move and multiply, and thus, p increases rapidly. For the constant strain rate to be maintained, the stress stops rising. As the dislocation-multiplication continues in proportion to the stress, p becomes high, and thus v should drop, which means stress should drop to lower yield point level. The stress required to deform the specimen decreases once yielding begins. The presence of marked yield point depends on the interaction energy (between the solute and the dislocation) and the concentration of the atoms at the dislocations. As carbon (and nitrogen) atoms can lock both screw and edge dislocations in ferrite (in mild steels), the substitutional atoms in FCC metal cause weaker locking of dislocations, the FCC metals exhibit yielding to a lesser degree.

Summarising the sharp yield point phenomenon, its occurrence depends on the sudden increase in the number of mobile dislocations. The precise mechanism responsible for this increase depends on the effectiveness of the pinning of pre-existing dislocations. If it is weak, then yield point occurs as a result of unpinning such as by substitutional solutes. However, if the dislocations are strongly anchored such as by interstitial atmospheres in BCC lattice, the yield point occurs due to rapid generation, and further multiplication of new dislocations.

STRAIN-AGEING

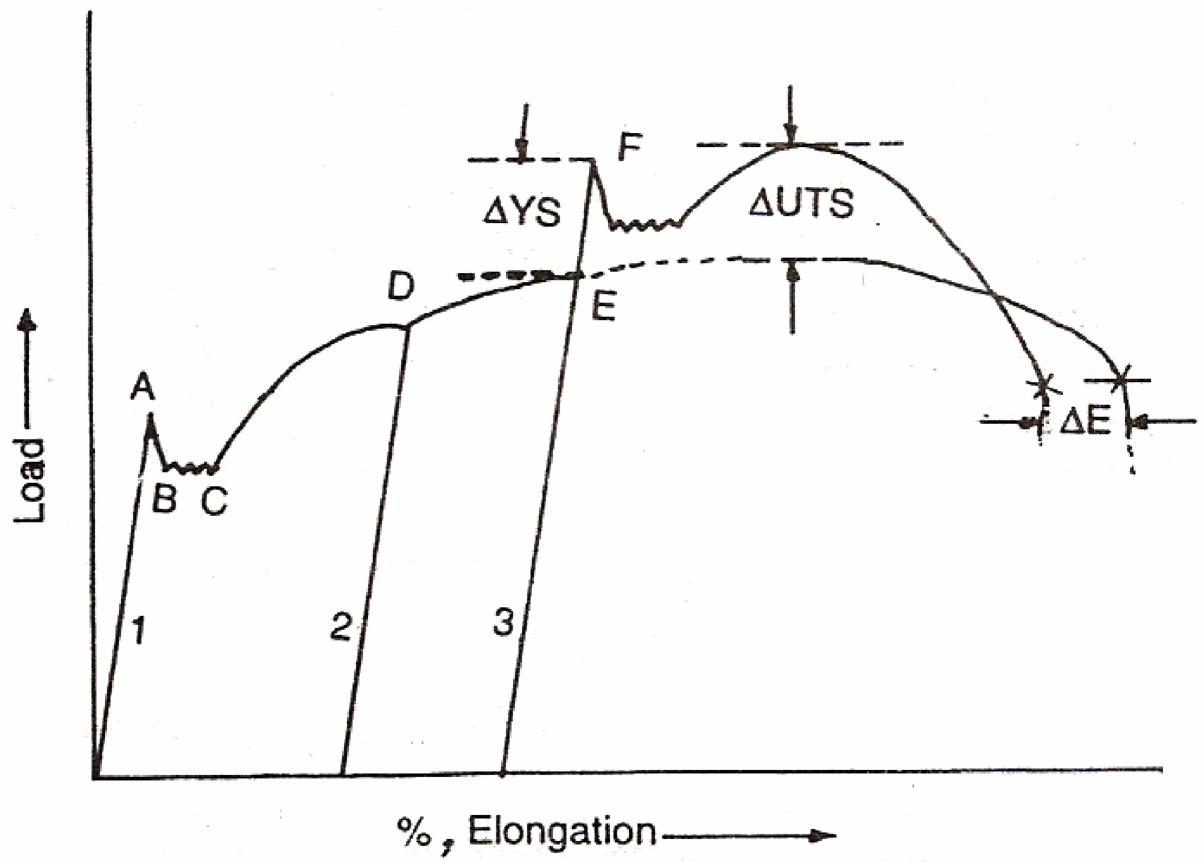
Strain-ageing has been known as long as the steel has been made. The change in properties due to strain-ageing could be detrimental, but if used with discretion, it can be a valuable and economical means ipf strengthening steels.

Strain-ageing has been defined as change in the properties of an alloy that takes place by the interaction of point defects—specially the interstitial atoms and the dislocations during, or after the plastic deformation.

(Interstitial solute atoms in BCC iron can interact with all types of dislocations). *If the change in the properties takes place after the plastic deformation (during the ageing period), then the process is called static strain-ageing or static strain-age hardening,* though it is more commonly termed as *strain-ageing.* But if the change in the properties takes place as the plastic deformation progresses, then it is called dynamic strain-ageing.

Fig. 4.90 illustrates load-elongation curve of low carbon steel, where A is upper yield point, B is lower yield point, BC is the Luders bands formation stage (this elongation is Luders elongation). From point C onwards, the specimen work-hardens and thus, the curve rises steadily and smoothly. If the plastic deformation of such a specimen of low carbon steel (in tensile test) is continued up to point D, and the specimen is then unloaded, and reloaded fairly soon, then it exhibits a curve of type (2), that is, on reloading, the specimen deforms elasti-cally up to the unloading point D, and the yield point is absent at the beginning of the plastic flow (at D), because the newly created dislocations have not been locked by Cottrell atmospheres of carbon and nitrogen atoms. As enough time was not given (before reloading the specimen) and moreover the diffusion at room temperature is quite sluggish, thus, the diffusion and the resulting segregation of these interstitial solute atoms to the new dislocations has not occurred.

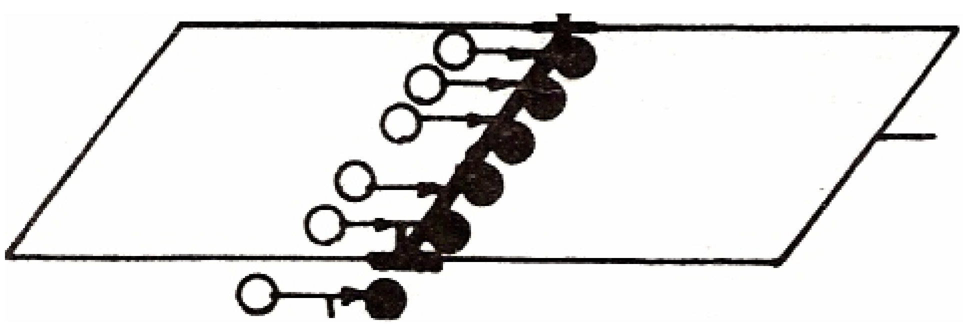
If the specimen is strained up to a point, say E, Fig. 4.90 and is then unloaded here. It is allowed to rest for several hours at room temperature, or a few seconds at 200°C. The specimen on reloading follows the curve 3, and the yield point is raised to point F, and the sharp yield point reappears. *This process in which yield point reappears and is accompanied by the following effects is known as strain-ageing or strain age- hardening:*



1. The yield stress is raised during ageing by *A YS.*
2. The ultimate tensile strength is raised by *MJTS.*
3. The ductility decreases as indicated by the decrease in total elongation by *AE.*
4. The yield point elongation (and thereby Luders band formation) takes place again. This elongation increases with ageing time.
5. Ageing causes increased working-hardening-coefficient, or increased rate of work-hardening.
6. Ageing causes low value of strain rate sensitivity, which is defined as the change in stress required to produce a certain change in the" strain rate at constant temperature.
7. Strain-ageing is not susceptible to overageing.

During (strain) ageing process (that is, during this time), a plastically deformed alloy reduces the energy of its strained lattice by the process of diffusion of interstitial solutes (carbon or nitrogen) to the dislocations.

The increase in its yield point and the reappearance of the yield point are due to this diffusion of carbon and nitrogen atoms to the dislocations during the ageing time to form new atmospheres of the interstitials, and thus anchor the dislocations, schematically illustrated in Fig. 4.91. As the activation energy for the return of the yield point on ageing is found to be in good agreement with the activation energy for the diffusion of carbon in alpha jron, this confirms above explanation. As the dislocations have been pinned, the stage is set to show as usual (as explained for appearance of sharp yield point) the upper yield point, the yield drop, the lower yield point, and Luders band formations. Strain-ageing is a time and temperature dependent process. In low carbon steels, strain-ageing at temperatures below about 100°C is almost entirely due to nitrogen atoms as the *solubility of carbon* at these temperatures is too low to produce any appreciable ageing effects. Nitrogen has higher solubility and higher diffusion coefficient in alpha-iron at any temperature (mainly because the size of nitrogen atom 0.72 A° is smaller than size of carbon atom 0.77 A°).



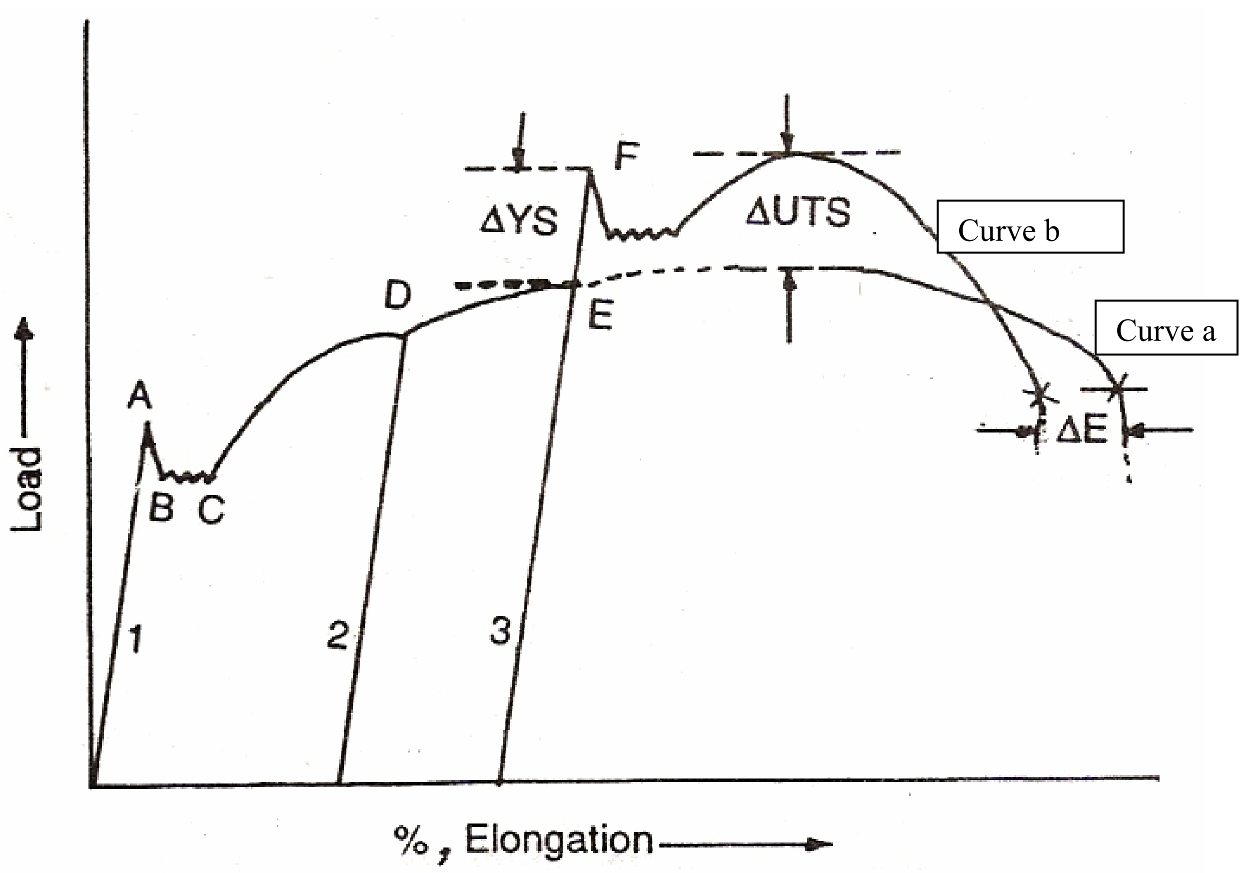
The concentration of interstitial solute atoms in solid solution in alpha-iron should be reduced to about 0.0001% or less toieliminate the effects of strain-ageing. It may be done by adding elements like aluminium,

vanadium, titanium, columbium or boron, which form stable carbides or nitrides etc. Though completely non-strain-ageing commercial low carbon steel is difficult to obtain, the usual industrial solution to this problem is to have skin-rolling of the steel and use it immediately before it can strain-age. The local plastic deformation by skin-rolling produces sufficient fresh dislocations (without atmospheres) so that subsequent plastic deformation can occur without a yield point, otherwise, the unsightly rough surface due to "stretcher strains' forms. The strain-ageing effects can approach their maximum at a concentration of only about 0.002% of the element. The change in yield stress is the most consistent criterion of indication of strain-ageing at all solute content and at all ageing time. The process of quench-ageing may take place along with the strain-ageing, but is not an essential part of strain-ageing. But if it does, the increase in properties due to strain-ageing is enhanced.

After the ageing time, the dislocations are firmly pinned by the solute atoms, and the dislocations are not unpinned at new upper yield stress (point F in Fig. 4.90) after reloading. Actually, new dislocations are generated at sites of stress concentration, such as grain boundary edges or inclusion interfaces. For a given total strain, therefore, the dislocation density is greater if an ageing step has been incorporated than if the strain is applied continuously, and thus, the rate of work-hardening is increased.

LITERATURE SURVEY

Strain ageing is observed in low carbon steel and result in an increase in strength and decrease in ductility. It is generally accepted that these effects are due to uncombined interstitial atoms such a carbon or nitrogen mifgrated to dislocation and locking them further as little as 0.00012 to 0.001 free carbon or nitrogen is sufficient to cause strain ageing.



The occurrence of strain ageing can be determined by a tension test for an annealed and normalized mild steel the stress-strain curve take the form of curve in figure. If the specimen is strained to point E and beyond the lower yield extension BC and unloaded immediately the stress-strain curve rejoins and follows the same curve.

If the material is susceptible to strain ageing unloading at E followed by ageing at room temperature or above result in the return of the discontinuous yield behaviour and the stress-strain curve b follows.

The yield point F is now higher than the flow stress E at the end of pre-straining. The increase in yield and the flow stress upon loading and ageing is the most universal indication of strain ageing. Generally there may also be increase in the ultimate tensile strength of the metal.

A standard size tensile strength specimen was machined from sheet stock with the rolling direction parallel to the testing direction and the tension test conducted at room temperature. For every strain ageing experiment of each steel work pre-strained in tension the increment in pre-strained were chosen. Specimen was aged at a particular temperature for some hours. So the stress-strain curves for all steel in the received condition were similar to

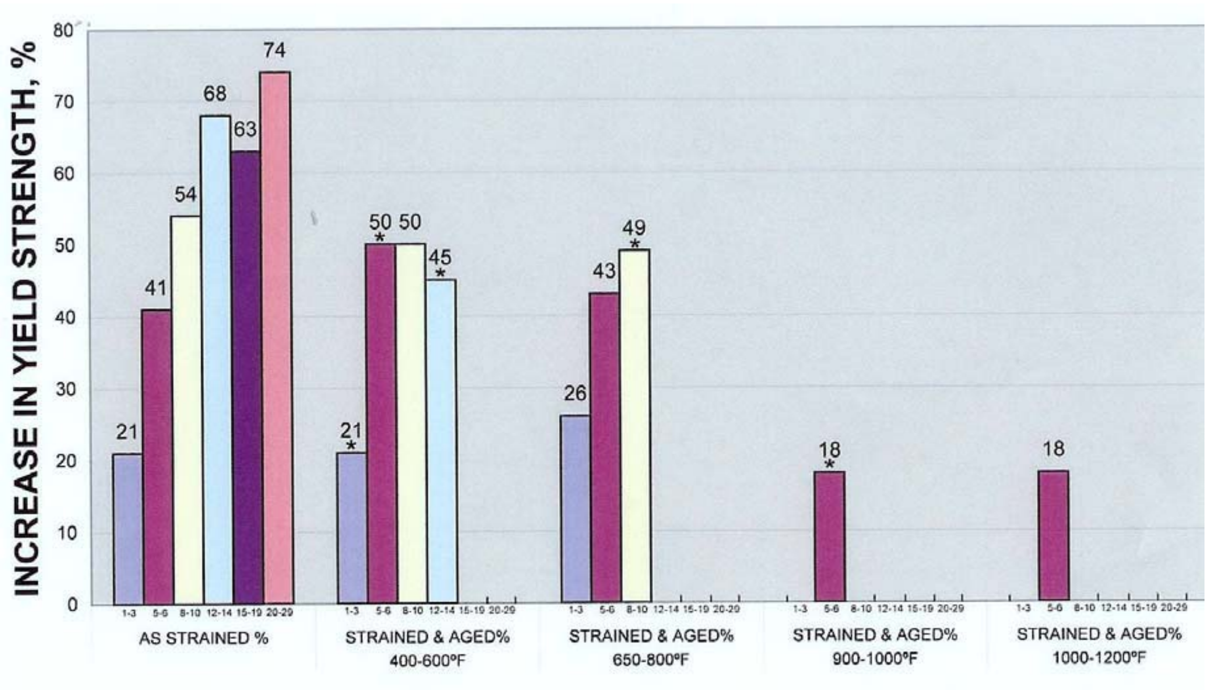


Figure 1. Increase in Yield Strength with Straining and Aging

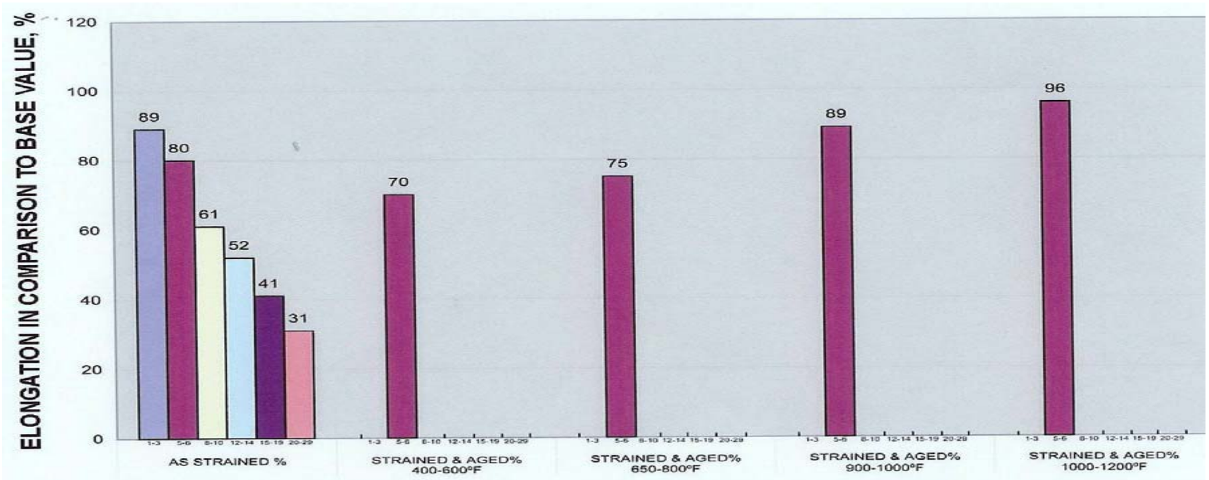


Figure 3. Decrease in Elongation with Straining and Aging

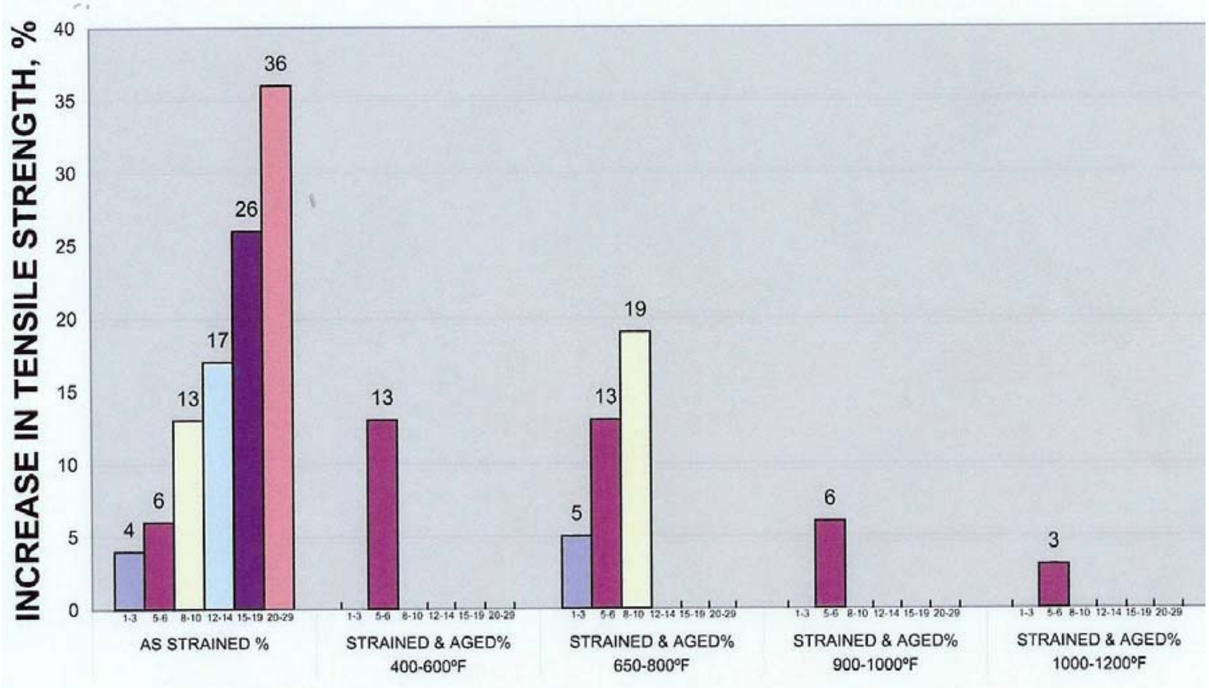


Figure 2. Increase in Tensile Strength with Straining and Aging

The effect of strain ageing on ductility was also measured , total elongation after strain ageing was used as a measure of residual ductility as plotting a function of pre- strained. IT indicates that low carbon steel is susceptible to strain ageing , strain increase ,upper yield points were observed and yield point elongation reappeared on straining and ageing. The relative low temperature at which strain ageing occurred and the fact that change were observed in both ultimate tensile strength and total elongation indicate that the straing ageing was due to interstitial solids and the potential of interstitial solutes judged by the carbon and nitrogen content in the steels. Oxygen has no effect on the strain ageing

METALLURGICAL CAUSE FOR STRAIN AGEING --

The alloying elements in the steel are dispersed into their characteristic microstructural constituents, predominantly iron and iron carbide. In the case of nitrogen and some of the carbon that is not absorbed in iron carbide, they are in the iron-rich phase as small individual atoms in interstices in the crystal structure. After the steel cools from rolling, over time, the carbon and nitrogen atoms migrate through the structure to the dislocations due to the distortion they create in the crystal lattice. The motion of these (small) interstitial atoms to the dislocations produces a stabilizing effect which increases the force necessary to cause the dislocation to allow slip. It now takes greater force to deform the steel, raising its strength. If both carbon and nitrogen are present, iron-carbon-nitrogen compounds (carbonitrides) can form that also restrict the motion of the dislocations and raises the strength of the steel.

The effect of temperature is important on the “aging” phenomenon in structural steels. Structural steels are more complex that sheet steels in that they contain relatively more carbon and alloy and have a more complex microstructure. As a result, the aging of the steel as measured by increases in strength and loss in toughness does not occur at room temperature. In general, temperatures in the 300 ^{o}F-700^{o}F range for periods of 1-5 hr are necessary to develop aging effects.

A second strengthening mechanism occurs when cold deformation (alone) is done to steels. When dislocations break away for their pinning interstitial atoms and begin the movement causing slip they begin to intersect with each other. A complex series of interactions between the dislocations occurs, causing them to pin each other, decreasing their mobility. The decreased mobility also results in higher strength, lower ductility and lower toughness. As a result, cold deformed steels already have lowered ductility and toughness before any strain aging occurs and when heating follows cold deformation, the loss in ductility and toughness is greater. It is this combination of events that is the most damaging to the toughness of structural steels. It is these two effects, the increased strength and reduction in ductility and toughness from cold strain followed by an additional strength increase and toughness loss through aging, that are the primary elements in strain aging.

Effects of Strain Aging on Strength and Toughness —

This explanation of the causes of strain aging fits quite well with the "aging" effects observed in steel products. The phenomenon was first observed in steels that were rolled and annealed. After being stored for weeks or months, during which time the interstitial atoms migrated to the dislocations, the yield point increased significantly and the ductility decreased. The material appeared to have "aged." For structural or pressure vessel steels, materials that were cold formed during fabrication by bending or rolling had increased strength and decreased ductility and toughness. When heated after forming, for example by preheating before welding or in low temperature stress relief, their strength was further increased and its ductility and toughness further degraded.

CONTROL OF STRAIN AGEING--- There is some well-established methods for control of strain aging but most are neither entirely effective nor practical. The first approach is to eliminate the presence of the interstitial elements, particularly the carbon and nitrogen that can cause this phenomenon. Since these elements are almost always present in structural steels and only small amounts are required to cause strain aging, this has proven to be either difficult or expensive to do on a regular basis. Special steelmaking procedures, such as vacuum degassing, i.e., subjecting the molten steel to reduced atmospheres to eliminate hydrogen and some nitrogen in the steel, should eliminate or reduce strain aging. This is both expensive and not entirely effective. Another approach is to deoxidize the steel with aluminium as well as silicon. Aluminium-silicon deoxidation is intended to not only remove dissolved oxygen from the steel as oxides but also to combine aluminium with nitrogen to form aluminium nitrides that help to control grain size during and after heat treatment. This should remove free nitrogen from the steel in the form of nitrides and eliminate one cause of strain aging. As the research cited below will demonstrate, some aluminium-deoxidized steels still appear to be susceptible, thus this approach has also not proven to be entirely effective. Finally, it might be expected that steels containing strong carbide–forming alloy elements such as chromium, vanadium and molybdenum would be less susceptible to strain aging, research shows that this has not proven to be the case either.

A procedure that is sometimes effective in reducing the toughness loss in strain aging is to apply a heat treatment after straining to cause “over aging” of the steel. This process is virtually the same as used to stress relieve weldments and requires heating the strained material to temperatures in the

$1000^{o}F$ to $1150^{o}F$ range. While this procedure is routinely applied to some products, for example some classes of pressure vessels, it is not often applied to bridges or other structures. Moreover, when applied to such large and complex structures, not only is this expensive but distortion and creep leading to shape change can occur, making this approach unrealistic. It has also been found in the research reviewed here that even this procedure is not effective for some steels; lost toughness is not always recovered during stress relief, probably due to other reactions and microstructural changes occurring during heating in this temperature range for extended periods of time, i.e., hours.

At the present time, although each of the steps outlined above can help to control or mitigate the effects of strain aging, there is no one procedure that will guarantee there will be no toughness loss due to strain or subsequent aging. One approach that is effective is to select steels that have sufficiently high toughness and low transition temperatures that losses in toughness by strain aging do not have a significant effect on service performance. The High Performance Steels that are designed with toughness levels that greatly exceed service requirements meet this requirement.

MICROSTRUCTURE TRANSITION BETWEEN WELDMETAL AND BASE METAL ----Microstructure transition of V-groove butt joint Welds is shown in Fig. The WM consists mainly of acicular ferrite, grain boundary ferrite, and a little side plate ferrite, as shown in Fig. (a). The coarse grain heat affected zone (HAZ), consists mainly of granular bainite particles, as shown in Fig. 4 (b), being coarser than that in BM and finer than in WM. The fine grain heat affected zone (HAZ), consists of a large amount of ferrite and granular bainite particles, as shown in Fig.4 (c).However, there is no big change in the microstructure. It is beneficial for both the strength and ductility in welded joints, when WM consists mainly of acicular ferrite. During the welding procedure, because of a very high cooling rate after welding. Low carbon Low alloy steels tend to be quenched, and the microstructure transition in HAZ almost has the same tendency.

The super critical HAZ is fully austenite and because of different cooling rates, martensite (very fast cooling), ferrite and bainite (fast cooling).

Ferrite and pearlite (not fast cooling), also including Widmanstatten ferrite will form after cooling. The microstructure in the CG HAZ of investigated steel consisting of granularbainite particle and acicular ferrite is coarser than that in BM, and also shows a higher Vickers hardness. However, no martensite is found in this region. The microstructure of the FGHAZ of the investigated

steel [seen in Fig. 4 (c)] consisting of refined acicular ferrite is finer than that in HAZ and WM is partially austenitizied, the microstructure is preserved ferrite, refined ferrite, and pearlite.The low temperature HAZ with the temperature peak below Ad cannot experience any phase transformation and this region is not easily distinguished from BM, which consists of ferrite, bainite, and retained austenite.

In general ship construction C-Mn steel plates are used, here the microstructure vary with nitrogen content in the metal it's also affect the weldability of plate. The presence of nitrogen during arc welding of HSLA steels affects final properties of their weld metal due to various effects of nitrogen on the weld microstructure. In particular, by contributing to (dynamic) strain aging processes, nitrogen decreases ductility of welds and raises their brittle/ductile transition temperature. Strain aging occurs in weld metal at temperatures of 100-300°C due to plastic deformation necessary to accommodate thermal/mechanical strains [2]. In multipass welds the strain aging causes embrittlement of the weld root after several heat cycles of the subsequently deposited beads. Multipass C-Mn welds containing different amounts of nitrogen, after applied cold strain of 10%and aging at 250°C for 0.5 hour, showed a substantial raise of the brittle/ductile transition temperature, and the impact strength could not be recovered by applying stress-relief heat treatment of 2 hours at 580 C

Microstructure of the as-deposited weld metal in the top layer of the welds was ferrite, with a minor amount of second phase, Fig. 1. All types of ferrite were present, i.e. grain boundary (GB) ferrite, side-plate ferrite and acicular ferrite. The second phase in 'low-N' sample//NO was mainly bainite/pearlite, and with increase of nitrogen content the second phase became martensitic, Fig.2, its

amount increased as well. With more martensite as the second phase, the dislocation density in ferrite of the top layer increased, and high density dislocation configurations appeared in the heat affected weld beads of the central and root portions of the welds. An increase of nitrogen content in C-Mn steel weld metal results in a greater fraction of martensite in the weld and consequently in a larger dislocation density in the ferrite.

The diffusivity of nitrogen is high than carbon, due to strain ageing more nitrogen interact with dislocation interstitially dissolved nitrogen (and/or carbon) during deformation, blue brittleness phenomena is occurred in steel welded plate .

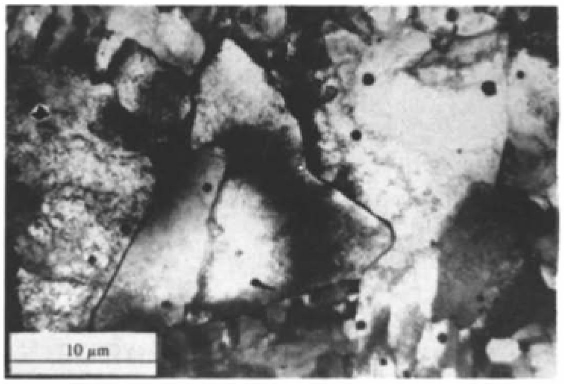


Fig.1. Fields of fine acicular ferrite, separated by coarser grain-boundaryferrite grains in low-N (#NO), as-deposited weld metal

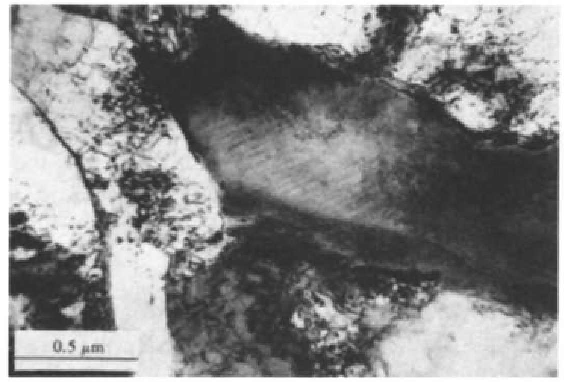


Fig.2. Second phase island of twinned martensite in acicular ferrite region of the as-deposited, high-N (#N3) weld metal.

<u>Mechanical properties of weld metal</u>------ In the weld metal zone to analyzed the morphology of weld metal zone it may be said that the yield strength of weld metal increases. Weld metal usually contain high density of dislocation which also contribute to increase in yield strength of carbon. The final results is that weld metal normally have higher tensile strength or yield strength than compare with base metal.

<u>Strain ageing in different steels</u> -- In the HSLA steel here kinetics of strain ageing is slower than the mild steel ,in HSLA steel High strength steel (HSS) for automotive application usually reveals a fair to middling balance of high strength and good ductility.In the HSLA steel the strain ageing phenomena is like a low carbon steel. The strain aging characteristics of a HSLAsteel made with vanadium rangingbetween zero and 0.1 pct and with two aluminum levels have been investigated for the as hotrolled condition. It has been shown that vanadium contents of 0.04 to 0.06 pct (a V/Nratio of 7 to 9) will result in the combination of almost all the active nitrogen as vanadiumnitride and suppresses natural strain aging. Vanadium in excess of this level resuits in the precipitation of vanadium carbide and the consequential precipitation hardeninggives an increase in the yield strength, tensile strength, and impact transitiontemperature without imparting further beneficial effect with regard to strain aging. Themechanical properties have been shown to be generally unaffected by the two different aluminum levels, and no grain refinement resulted from either the vanadium or aluminium additions. This absence of grain refinement and the precipitation hardening results in anincrease in the impact transition temperature with increasing vanadium content, althoughthis increase is initially slow whilst the active nitrogen content is being reduced

In the dual phase steel it shows some different interpretation, it's shows a island of martensite on the ferrite matrix Tensile properties of dual phase steel were seen in which compares the engineering stress–strain curves under different pre-straining and ageing conditions, dual phase steels, prior to any ageing, have rounded stress–strain curves due to the presence in the ferrite of unpinned dislocations produced by the volume change that occurs when the austenite regions transform to martensite. Conventional HSLAsteels, which have a ferrite, pearlite, carbonitride precipitate structure, have extensive yield plateaus, as initially they contain no free dislocations [16].When dual phase steel samples were aged at 100or 200 _C for 30 min after pre-straining in tension by 2 or 4%, they too develop yield plateaus due to immobilization of the free dislocations. Static strain ageing in microalloyed dual phase steel was studied by the measurement of the changes in yield stress due to ageing in specimen pre-strained in the range of 2 and 4%. The obtained results from this study as follows:-

(1) The smooth stress–strain curves in dual phase steel are a result of the motion of free dislocation in the ferrite. These dislocations were produced

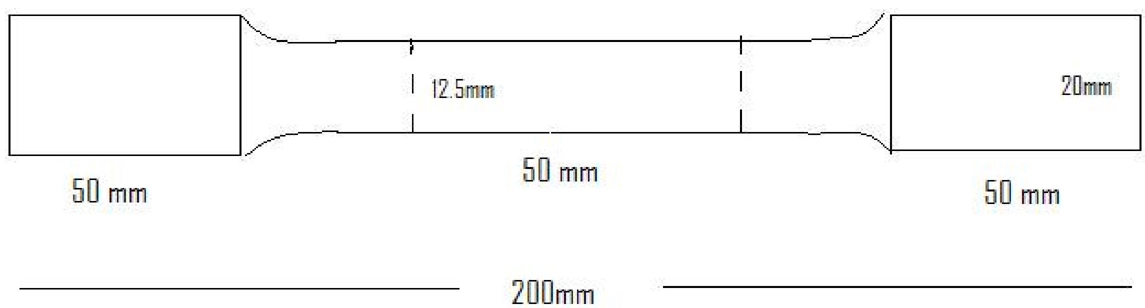
by the volume change that occurs when the austenite regions transform to martensite.

(2) The ageing treatment at 100 _C caused an increase in YS. This is due to the formation of solute atom atmospheres around dislocations; at 200 _C caused a reduction in the yield strength due to overageing resulted from tempering that starts in martensite

.**STRAIN AGEING IN WELD METAL:-** The cause of the embrittlement is the plastic strain accompanying shrinkage of welds which can spread to surrounding base plate and heat affected zones. Since the shrinkage strain occurs simultaneously with cooling from welding, it induces strain aging and resultant loss of toughness. The effects of this type of strain aging are greatly increased when weld discontinuities are present since they provide strain concentrators in the weld or heat affected zone that can exacerbate the strain aging effect. These discontinuities can be weld cracks or lack of fusion in weld areas or welds placed over poor joint fit-up.

Experimental procedure:

Low- carbon steel sheet having carbon composition 0.13% and 0.8% manganese was taken. The strips were cut in the rolling direction bunches of some 10 pieces of strips were tagged by welding, the tensile specimen were prepared by machining in the universal milling machine. The specimen dimensions are shown in figure.



After that the specimen were given homogenised annealing at 950 C. The specimen were tested in INSTRON 1195 in the following manner two dummy samples were tested and total strain e_t at fracture was found out, the assigned pre- strain values 3%, 6% and 9% were calculated from these (e_t) values.

In the strip chart recorder of INSTRON 1195 machine straight lines were drawn parallel to the tensile dummy curves. The number of such curves was drawn corresponding to the no. of specimen to be pre-strained. The specimen to be pre-strained fitted in the machine and simultaneously the pen-stylus was exactly put at the origin pre-strain curve of stress-strain. Pen-stylus move in proportion movement of the cross head. The movement of pen-stylus touch the parallel line touch the assigned pre-strain and loading was stopped then specimen was unloaded. After that the specimen was taken out heated in oven under the oil bath with accuracy of +1 or -1C by the thermocouple. The different specimens were aged at 120C.

The schedule for pre straining and ageing are shown in TABLE-1

TABLE-1

S No	Percentage pre strain	Temperature of strain ageing (C)	Time of strain ageing
1	3	120	2
2	9	120	2
3	3	160	2
4	9	160	2
5	3	120	6
6	9	120	6
7	3	160	6
8	9	160	6
9	6	140	4

RESULTS AND DISCUSSION — As mentioned previously the welded or nonwelded tensile samples were prestrained & strainaged according to the schedule shown in table – (1). The Δy corresponding values are shown against each of the strain ageing schedules.

By analyzing the Δy, regression equation were formulated by applying of statistical design experiments.

The equation is of the type: ---

$$\Delta Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 + b_{123}X_1X_2X_3 \quad \text{----------------------------equation-(1)}$$

For non- welded samples: - TABLE-2

S No	Percentage pre strain [x_1]	Temperautre Of strain Ageing in^{0}C [x_2]	Time of strain ageing in hours [x_3]	ΔY[Mpa] (Change in yield stress Due to Strain ageing)	Mean ΔY[Mpa]
1	3	120	2	14.5	14.3
				14.1	
2	9	120	2	12.2	12.6
				13.0	
3	3	160	2	23.4	23.6
				23.8	
4	9	160	2	18.7	18.5
				18.3	
5	3	120	6	21.0	21.4
				21.8	
6	9	120	6	15.5	15.7
				15.9	
7	3	160	6	29.1	29.4
				29.7	
8	9	160	6	26.5	26.2
				25.9	
9	6	140	4	19.4	19.8
				20.2	

the equation for non welded sample is developed from equation (1)

$$\Delta Y = 20.21 - 1.96X_1 + 4.22X_2 + 2.96X_3 - 0.11X_1X_2 - 0.26X_1X_3 + O.41X_2X_3 + 0.78X_1X_2X_3$$

For welded samples: TABLE-3

S No	Percentage pre strain [x_1]	Temperautre Of strain Ageing in^{0}C [x_2]	Time of strain ageing in hours [x_3]	ΔY[Mpa] (Change in yield stress Due to Strain ageing)	Mean ΔY[Mpa]
1	3	120	2	12.3	12.8
				13.3	
2	9	120	2	10.4	10.2
				10.0	
3	3	160	2	19.3	19.8
				20.3	
4	9	160	2	15.2	15.7
				16.2	
5	3	120	6	19.6	19.4
				19.2	
6	9	120	6	14.2	13.9
				13.6	
7	3	160	6	20.6	20.4
				20.2	
8	9	160	6	17.5	17.2
				16.9	
9	6	140	4	16.9	17.4
				17.9	

The given below expression for the welded samples is ----

$\Delta Y = 16.18 - 1.93X_1 + 2.1X_2 + 1.55X_3 - 0.1X_1X_2 - 0.25X_1X_3 + 1.025X_2X_3 + 0.475X_1X_2X_3$

Analyzing equation – (2), it can be seen that the extent of prestrain has got negative influence over the ΔY value. As revealed by its coefficient that is -1.96 it indicates that the temperature of strain ageing has got positive influence on ΔY, which is a coefficient of +4.22. The time of strain ageing has got also a positive influence on strain ageing behaviour as shown by that is coefficient of +2.96 of the time of strain ageing

These coefficients explain the fact that temperature of strain ageing has got more positive influence on ΔY than the time of strain ageing. The interaction coefficients are very small and negligible as compared with coefficients of X1, X2 & X_3.

On comparing equation – (2) & equation-(3) the following can be seen. The b_0 coefficient value of the welded sample is 16.175MPa in comparison to b_0 (20.21MPa). This indicate that the extent of strain ageing in welded sample is less due to this the ΔY is less in welded sample. These factors are attributed to the fact the dislocation density of weld metal is higher than nonwelded sample.

As one of the requirement of strain ageing phenomena is low initial dislocation density. The extent of strain ageing in nonwelded samples indicated by its b_0 value in equation – (2) is high, its comparison the extent of strain ageing in welded sample is less as indicated by the b_0 value in equation –(3) , it's state that the welded specimen have a high dislocation density. The effect of other coefficient of equation – (3) are similar the coefficient of equation – (2) .These means for welded samples also increased the extent of prestrain reduces extent of strain ageing(ΔY) .Increase in the strain-ageing temperature the value of ΔY increased, increase the time of ageing has also got influence on value of ΔY. However the influence of temperature of ageing is much more pronounced than the affect of time of ageing.

This can be explained on the basis of influence of temperature on the diffusion of carbon than the influence of time on the same. The strain ageing is the result of locking of the dislocation by the carbon atom.

These results need verification by conducting further test on various samples.

CONCLUSIONS –

1) Welded low carbon steel samples are found to respond strain ageing .
2) In both welded and non welded samples the effect of prestrain have got negative influence on extent of strain ageing .
3) The temperature of strain ageing has got large positive influence on the extent of strain ageing .
4) The time of strain ageing has positive influence on strain ageing though its influence is less than that of the temperature of strain ageing.
5) The extent of strain ageing in the welded sample is less than that in the non-welded sample.

REFRENCES:----

1-Strain-Aging of Vanadium, Niobium or Titanium-Strengthened High-Strength Low-Alloy Steels.,M.S.RASHID

2- D. V. WILSON and B. RUSSELL, Acta. Met. 8. 36 t 1960)

3- A. H. COTTRELL and B. A. BILBY, Proc. Phys. Sm. Lord.A62, 49 (1949).

4-A. H. COTTRELL and G. M. LEAK. J. Iron St. Inst. 172.301 (1952).

5-A. H. COTTRELL and A. T. CHURCHMAN, J. Iron St. Inst.162, 271 (1949).

6-Speich GR. Physical metallurgy of dual-phase steels. In: Kot RA, Bramfitt BL,editors. Fundamentals of dual-phase steels.Warrendale: AIME; 1981. p. 3–45

7-Influence of straining and ageing on the room temperature mechanical propertiesof dual phase steelSuleyman Gunduz *, Atilla Tosun 1Karabük University, Technical Education Faculty, Department of Materials, 78200 Karabük, Turkey

8-Influence of Post Weld Heat Treatment on the Dynamic Strain Aging of C-Mn SteelsD. Wagner, J.C. Moreno and C. Prioul

9-Cheng L., Bottger A., Mittemeijer E.J., ***Met. Trans. A,*** **23A** (1992) 2737.

10-Fergusson P.,Jack K.H.,Quench-aging and strain-aging of nitrogen-ferrite, Proc. Heat Treatment Conf., Birmingham 1981, (The Metals Society) 158.-

11-MECHANICAL METALLURGY by G.H DIETER

12-RHYSICAL METALLURGY by VIJENDRE SINGHK.

13- Murata, H. Morise, M. Mitsutsuka, H. Haito, Transactions of the Iron and Steel Institute of Japan 24 (1984) B309.

14-Baird, J. D., “Strain Aging of Steel; A Critical Review,” Iron Steel, 36, 186-192, 326-34, 368-373, (May-Aug. 1963)

15-Baird, J. D., “The Effects of Strain Aging due to Interstitial Solutes on Mechanical properties of Metals,” Met. Rev., 5, 1-18 (Feb. 1971).

16-. Cottrell, A. H. and Bilby, B. A., “Dislocation Theory of Yielding and Strain Aging of Iron,” Proc. Phys. Soc. London, 62, 49-62 (1949)

17-. Wilson, D. V., and Russel, B., “The Contribution of Precipitation to Strain Aging in Low Carbon Steels,” Acta Mtall., 8, 468-479 (July 1960)

18-. Osborn, C. J., Scotchbrook, A. F., Stout, R. D., and Johnston, B. G., “The Effect of Plastic Strain and Heat Treatment,” Welding J., 14(8), Res. Suppls (1949)

19-. Rubin, A. I., Gross, J.H., and Stout, R. D., “Effect of Heat Treatment and Fabrication on Heavy Section Pressure Vessel Steels,” Welding J., 24(4), Res. Suppls (1959)

20-. Succop, L. N., Pense, A. W., and Stout, R. D., “The Effects of Warm Overstressing in Pressure Vessel Steel Properties,” Welding J., 49(8), Res. Suppls (1970)

21-. Herman, W. A., Erazo, M. A., DePatto, L. R.,Sekiwaza, M. and Pense, A. W., ”Strain Aging of Microalloyed Steels”, Welding Research Council Bulletin 322, April, 1987.

22-. Khristenko, I. N., "Effect of repeated strain aging on the tendency of carbon steel towards brittle failure," Metal Science and Heat Treatment (English Translation of Metallovedenie i Termicheskaya Obrabotka), **29**, p.110 (1987)

23-. Sorsa, I. and Vierros, P., "The effect of welding on the mechanical properties of cold formed structural steels," Scandinavian Journal of Metallurgy, **16**, p.134 (1987)

24-.Yurioka, N., "TMCP steels and Their Welding," Welding Research Abroad, V.43 (1997)

25-. Dobi, D., Kocak, M., et. al., "Evaluation of fracture properties of cold deformed 450 YS TMCP steel," Proceedings of the 13th International Conference on Offshore Mechanics and Arctic Engineering **3**, p. 315 (1994)

26-. Ule, B., Vojvodic-G., J. and Lovrecic-S., M., "Effect of strain-aging on the fracture toughness of some structural grade steels in the nil-ductility temperature range," Canadian Metallurgical Quarterly, **35**, p.159 (1996)